CONTAMINANTS, TOXICITY AND WILDLIFE MORTALITY AT OIL PRODUCTION SITES IN WESTERN SOUTH DAKOTA

FINAL REPORT

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ABSTRACT

Chemicals at oil production sites can be hazardous to migratory birds and other wildlife. Oil, grease, and other chemical wastes related to well drilling are commonly stored in pits at oil production sites. Oil lost at valves is frequently caught in open containers. Oil production sites are located in arid regions of South Dakota where wildlife mistake open pits for wetlands and are often attracted to them. The Service studied the chemical composition and toxicity of oil pit liquids and searched oil production sites for dead wildlife.

Liquids and/or sediments from 31 pits located in Fall River and Harding Counties were evaluated for oil and grease in 1992. Oil and grease concentrations were at levels known to reduce benthic invertebrate numbers in all liquid samples analyzed. Due to a decline in the number of pits, only 15 Harding County pits were evaluated in 1993. Oil and grease concentrations were at levels similar to those found in 1992 in only 2 of 15 samples analyzed.

Forty pits were searched for dead wildlife in 1992 and 15 were searched in 1993. Dead wildlife, especially small mammals and birds were found around oil production sites. Salvaged carcasses were partially or totally covered with oil. Studies of scats indicated that predators consumed birds that died from oil exposure.

Electrical conductivity of 17,000 μmhos/cm has been shown to significantly reduce duckling growth. In 1992 and 1993, electrical conductivity in 4 pits equalled or exceeded 17,000 μmhos/cm. Electrical conductivity of pit liquids also could impact the diversity and abundance of aquatic invertebrate and plant species in and around pits.

The best method for preventing impacts to wildlife from chemical wastes at oil production sites is to totally eliminate wildlife contact with the waste liquids. Colored flags on guy wires had been installed at some pits to scare birds and other pits had been covered with nets. Flagging is ineffective at detering birds (Esmoil, 1991). Properly maintained netting can be an effective deterrent for larger birds. However, the best way to prevent wildlife mortality is to store waste liquids in closed tanks until they can be reinjected back into the ground. Many oil companies have begun extensive liquid reinjection efforts, thus making pits unnecessary.

The conclusions of this study are that pit liquids and sediments contained high concentrations of oil, grease, and other unidentified toxic chemicals that through contact or ingestion, could immobilize or cause mortality to birds and other wildlife. Several oil companies have initiated management strategies which minimize hazards to wildlife.

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INTRODUCTION

Waste liquids associated with oil production are sometimes disposed of in open pits. These liquids may consist of oil residues, other petroleum products, chemicals used in drilling operations, or high salinity water. At oil production sites, leaks at valves are frequently captured in open half-barrels.

Direct and indirect wildlife mortality, especially to birds, can occur from exposure to chemicals in pits. Indirect mortality occurs from oil on the feathers causing loss of flight, loss of thermoregulation, and entrapment resulting in drowning. Ingestion of small amounts of oil can adversely affect reproduction in birds, and small amounts of oil transferred from feathers to eggs during incubation can cause embryo mortality (Holmes et al. 1985; Olsen et al. 1990). Elevated concentrations of salts and other dissolved solids in pit liquids can be toxic to waterfowl and probably other wildlife (Swanson et al. 1988). Unidentified chemicals in the pits may cause other toxic effects to wildlife. Pit liquid quality is influenced by: (1) the presence of naturally occurring elements, (2) by chemicals released during well installation and production, (3) routine pumping to drawdown liquid levels, and (4) dilution from precipitation.

Thousands of migratory birds have perished in open pits containing oil production liquids in Wyoming, Texas, and other western oil-producing states (Flickinger 1981; Flickinger and Bunck 1987; Esmoil 1991). Waterfowl and small passerine birds were most susceptible to pit mortality. However, endangered species were reported to have died in some pits (Flickinger and Bunck 1987); and mammals, amphibians, and reptiles died in pits containing styrene tar in Texas (Flickinger 1981).

The magnitude of annual mortality to migratory birds and other wildlife from oil pits in South Dakota is unknown and difficult to determine. Birds fly away to die or are consumed by predators. Searches of pit areas probably reveal only the dead birds that recently died, which may represent a small percent of total mortality. Many birds that die or are crippled by exposure to liquid wastes at oil production sites are believed to be carried off by predators. Balcomb (1986) evaluated the time required during a 5-day test, for songbird carcasses to disappear after being placed in corn fields. In 7 trials, 62 to 92% of the carcasses disappeared the first 24 hours. Carcass losses were greater during the first 24-hour period than on subsequent days. Scavengers removed 72 of 78 carcasses (92.3%) over the 5-day test.

First year results on oil pits studied in South Dakota in 1992 were reported by Henry and Ruelle (1993). Oil pit studies were continued in 1993. This final report contains the results of studies conducted on western South Dakota oil pits in 1992 and 1993. Liquid wastes produced at oil production sites are often toxic to wildlife. Detrimental wildlife impacts identified at oil production sites substantiated the need to develop new preventive measures. This study was done in cooperation with the South Dakota Department of Game, Fish and Parks.

Oil exploration is expanding in South Dakota. Currently, most oil production is in Harding County with some in Fall River County. The same companies that are operating in these 2 counties, plan future wells in Butte County.

The objectives of this 2-year study were to: (1) document wildlife mortality by species, (2) determine the toxicity of pit solutions, and (3) identify methods of preventing wildlife mortality at oil production sites.

STUDY AREA

Oil production in South Dakota occurs primarily in the northwestern and southwestern parts of the state. Oil pits in Fall River and Harding Counties were evaluated in 1992 (Table 1, Figure 1). Most oil production, and consequently, the largest number of oil pits in South Dakota occur on private land in Harding County. Harding County is a semi-arid region with average annual precipitation of 39.99 cm. The rolling prairie is interspersed with intermittent creeks and stock ponds. Prairie grasses are the dominant vegetation in South Dakota oil production areas.

Studies in Fall River County were discontinued in 1993 because of a decline in the number of pits. Therefore, only pits in Harding County were evaluated (Table 2). Oil pits ranged in size from about 3 by 6 meters up to about 20 by 40 meters. The amount of liquid in the pits varied from none to nearly full. About one third of the pits sampled in 1993 contained clear liquid that appeared to be mostly rain-water runoff. There was no oil sheen on the surface of these pits, although black/gray oil sludges were present in the sediments. The oil sludges were present at the liquid-pit bottom interface or at some sites they were buried under 15 to 20 cm of silt. Oil floated to the surface when the buried sludges were disturbed.

Some sites were well maintained and relatively clean, whereas, at others, oil had been spilled near tank batteries or outlet pipes. Many of the pits we sampled in 1992 were filled in by 1993 and the half barrels commonly used to catch oil drips had been removed. It appears that between 1992 and 1993, many of the oil companies cleaned up their production sites, and reinjected waste liquids back into wells instead of disposing of them in pits.

METHODS

Oil production sites were visited periodically in the spring, summer and fall of 1992 and 1993 to collect liquid and sediment samples, and/or search for dead wildlife, and record the general condition of the production sites and pits. Forty pits were searched for dead wildlife in 1992. In 1993, dead wildlife searches were conducted on 15 pits. Searches for dead birds and other wildlife were made in the immediate area (a maximum distance of 100-meters) of each site. Federal and state laws prohibit the illegal killing of migratory birds. Dead birds recovered from the sites were used by Service law enforcement personnel as evidence of violations of the Migratory Bird Treaty Act, and delivered to the Smithsonian Institute for species identification.

In 1992, 26 composite liquid samples and 29 sediment samples were collected from 31 pits located in Fall River and Harding Counties. Most sediments were collected from pits containing liquid but a few were collected from dry pits. These samples were analyzed for oil and grease by the Mississippi State University Chemical Laboratory. Elevated concentrations of sodium, that contribute to electrical conductivity, are present in some pit liquids and wetland waters. In addition, some western South Dakota soils contain elevated concentrations of selenium that accumulates in wetland waters. Therefore, liquid samples from 15 oil pits were analyzed for selenium by the Oscar E. Olson Biochemistry Laboratories at South Dakota State University. Water quality characteristics including: sodium, sulfate, nitrate, bicarbonate, carbonate, hardness, alkalinity, electrical conductivity, percent sodium cations and pH were analyzed by the Water Resources Research Institute at South Dakota State University in Brookings, South Dakota.

Fifteen composite liquid and sediment samples were collected from Harding County pits in June 1993. Liquid and sediment samples were analyzed for oil and grease by the Geochemical Environmental Research Group at Texas A&M University. Liquid samples were analyzed for selenium and water quality characteristics by the same laboratories used in 1992.

Water samples were collected from 2 wetlands in each county located west of the Missouri River in South Dakota in 1993. These samples were analyzed for sodium, selenium, and electrical conductivity by South Dakota State University.

Predator scats were collected from the same areas where 17 dead birds were found in 1993. The scats were placed in plastic bags in the field and frozen. In the laboratory, the scats were submerged in plastic cups filled with water. Visual observations for oil on the surface of each cup were made after 24 hours. The scat material was removed from the plastic cups, placed in a petri dish, teased apart, and foods identified using a binocular microscope.

Seed germination bioassays were conducted with each pit liquid in 1992 and 1993. Ten radish seeds were wrapped in an unbleached paper towel, placed in a plastic cup, and then saturated with test liquid. Surplus liquid was decanted from the cups. Control seeds were exposed to water from the Fort Pierre, South Dakota city well. The cups were covered with plastic wrap, and the seeds were kept at room temperature under 8 hours of light. Seeds were checked for germination at 12-hour intervals for 96 hours. Germination was recorded when the seed coat ruptured and a root was visible.

Bioassays were conducted with liquids collected from pits in 1992 and 1993 using the aquatic invertebrates, Hyalella azteca (scuds) and Daphnia magna (daphnids). Two life stages, 2-day old and adult, of each invertebrate were used in the bioassays. Five each of either adult daphnids, young daphnids, or young scuds were exposed in individual assays to approximately 20 ml of oil pit liquid in plastic cups. Adult scuds were exposed to approximately 150 ml of oil pit liquid in plastic cups. A well water sample was used as a control for each species and life stage. The test solutions were aerated prior to initiation of the bioassays, and the solutions were replaced in each test vessel after 48 hours to maintain the chemical strength of the solution and to ensure an adequate oxygen supply. Bioassays were done at room temperature with 8 hours of light. Invertebrates were not fed during the 96-hour test. Assays were checked for survival every 24 hours for 96 hours. Immobility was the criteria used to indicate mortality. Correlations were used for statistical analyses.

RESULTS AND DISCUSSION

Wildlife Mortality

From January through October 1992, 10 birds, one long-eared bat (Myotis evotis), 11 unidentified small mammals, and nine cottontail rabbits (Sylvilagus floridanus) were found dead at oil production sites during infrequent spot checks. Bird carcasses found in April included one blue-winged teal (Anas discors) and one killdeer (Charadrius vociferus). Carcasses found in July consisted of one house finch (Carpodacus mexicanus), two barn swallows (Hirundo restica), one common snipe (Gallinago gallinago), one Northern rough-winged swallow (Stelgidopteryx serriopennis), one lark sparrow (Chondestes grammacus), and one Brewer's or clay-colored sparrow (Spizella breweri or S. pallida). Some unidentified small mammals but no birds were found in October 1992. The small mammals died in half barrels and other open containers. Live aquatic invertebrates or dead, oil-covered invertebrates were observed in the shallow liquid around the edges of numerous oil pits. Locating dead birds in Harding County in October was hampered by snow cover. Fall River County had only one active pit in October and no carcasses were found there.

Hydrogen sulfide gas is more predominant in Fall River County than in Harding County. Warning signs at the entrances to oil production sites in both counties state that hydrogen sulfide gas may be present. No wildlife mortalities were directly attributed to the gas. No dead wildlife were recovered from flare pits used to burn off waste gases.

In 1993, one dead bird was found at each of two pits and 17 dead birds were found at another pit. Many of these birds were covered with oil. Wildlife mortality is difficult to quantify at oil production sites because carcasses of dead birds and other wildlife are difficult to recover. Several factors could have influenced the number of carcasses found. The sampling effort was limited to three search visits per site. Bird carcasses could have either decayed or been scavenged by predators before recovery. Even birds dying a day or two before our visits were probably scavenged quickly, as evidenced by predator tracks near the pits and numerous predators observed in the area. Birds that died in oil pits quickly decomposed, and often only bird parts were found. In addition, many birds may sink to the bottom of pits and go undetected.

Searches for dead birds were confined to the edges of the pits and to the area in and around the production sites. Birds that died and sank in the middle of larger, deep pits could not be recovered by our search methods. Flickinger and Bunck (1987) observed the fate of various marked bird carcasses placed on oil pits. They found that some of the smaller species placed on the surface soon sank, reappeared at the surface in a few days, then sank again. Smaller birds sank faster than larger birds. Oil on the pit surface can greatly increase the ambient temperature of the liquid. Although it was not quantified, we noted that pit solutions containing oil were warmer than pits that did not. Flickinger and Bunck (1987) found that oil pit temperatures were significantly greater than air temperatures, and they stated that the higher temperatures of the pits may cause faster decomposition of carcasses.

Some pits are not oily enough to entrap birds but may contain enough oil or other chemicals to be toxic when repeatedly ingested. Birds not entrapped but affected by contaminants could leave the pit areas and/or hide in vegetation making them extremely difficult to locate during searches. We observed passerine birds, primarily swallows and kingbirds (Tyrannus spp.), fly down to the pit surface to drink or catch insects and then fly off to perch nearby. Three of the dead birds we found were swallows. Flickinger (1981) found a high percentage of passerine birds and shorebirds in styrene tar pits in Texas and suggested that insectivorous birds may be attracted to pits by trapped insects. Feeding on contaminated insects by swallows and flycatchers may make them more susceptible to sublethal impacts, including reproductive impairment. Many shorebird tracks were observed at a majority of the pits. We observed as a killdeer walked under a net covering a pit and down to the liquids' edge where it subsequently got oil on its feathers. The bird could not fly and was captured. A large number of the migratory birds that are impacted by these pits may be passerines and shorebirds, including some neotropical migrant species whose populations are declining.

Wildlife Exclusion Methods

Various methods were employed by oil companies to scare birds away or to physically exclude them from the pits we studied. Pit designs and wildlife exclusion methods varied. Pits with steep, unvegetated sides discouraged walk-in use by wildlife. Many pits did not have any deterrents, except flagging which consists of colored flags attached to support wires stretched across pits. Flagging is required by South Dakota State Law (South Dakota Administrative Rules 1987). Flag support wires often sagged and extended into the pit liquid, and we frequently observed birds using them as perches. Flagging and scare devices, such as noisemakers, have been shown to be ineffective and are totally inadequate at excluding wildlife from the pits (Esmoil 1991).

One of the most common wildlife exclusion methods was to cover the pit with a synthetic fiber net stretched over a frame. Small, rectangular shaped pits are more easily covered by nets. Nets with mesh small enough to exclude small birds need a sturdy frame and are difficult to maintain because snow and ice collect on them causing tears, sags or complete collapse. New nets were not inspected and existing nets were not maintained in many cases, resulting in large holes at seams, where pipes went through, or where small mammals chewed through. Netting, if maintained, reduces exposure of larger wildlife species to pit liquids but does not keep out all small passerine birds, small mammals, insects, snakes, etc. that are important in food chains.

Net seams need to be tightly sewn together and the edges of the net buried where it contacts the ground to effectively exclude wildlife. Covering the outside of the net with wire mesh up to about 50 cm from the ground prevents wildlife from chewing or excavating entrance holes. Small migratory birds and other wildlife have been observed passing through the nets covering pits. Vegetation control around pits may make them less attractive to birds and other wildlife. Nets are expensive and not easily moved to another location when a pit is reclaimed. Mice and other small mammals are attracted to half barrels which are open at the top. The best wildlife exclusion on half barrels is a cover made of expanded metal.

Tanks were used at some sites to hold liquids until they could be reinjected back into wells similar to those from which they originated. This increasingly popular way of disposing of wastes is the best method for preventing wildlife from coming into contact with toxic wastes associated with oil production sites. Companies with permitted reinjection wells frequently contract to reinject waste liquids for other companies.

Contaminants in Liquids and Sediments

Oil and grease concentrations in liquids ranged from 0.50 to 813.00 parts per million (ppm) and oil and grease concentrations in sediments ranged from 710.00 to 212,000.00 ppm dry weight in 1992 (Table 3). In 1993, oil and grease concentrations in liquids ranged from 0.00084 to 1.64984 ppm and oil and grease concentrations in sediments ranged from 1.69 to 1,000,000.00 ppm dry weight (Table 4). Oil and grease declined in liquids but increased in sediments between 1992 and 1993 (Tables 3 and 4). In 1992, the mean concentrations of oil and grease in 26 liquid and 26 sediment samples were 46.72 and 30,162.35 ppm, respectively (Table 5). In 1993, the mean concentrations of oil and grease in 15 liquid and 15 sediment samples were 0.15 and 249,970.00 ppm, respectively (Table 5). The decline of oil and grease in liquids collected in 1993 may have occurred because some of the pits were no longer used, they filled with rainwater, and the oil and grease settled to the bottom. The increase of oil and grease concentrations detected in 1993 sediments may have been due to settling out, or because smaller pits with more concentrated oil and grease were sampled, or because the liquid level had subsided, thus exposing sediments containing higher concentrations.

Eighty-five percent of the liquid samples collected in 1992 and 1993 had oil and grease concentrations less than 10.00 ppm, and only 2 samples had concentrations over 100.00 ppm (Tables 3 and 4). Sixty five percent of the sediments contained over 10,000.00 ppm oil and grease in 1992. High concentrations of oil and grease in sediments were not necessarily correlated with high concentrations in liquids.

Oil and grease in water can significantly affect benthic invertebrate populations. Woodward and Riley (1983) found that water containing 46 to 85 ppb oil reduced the number of benthic invertebrate species and their biomass. By these criteria, liquids from all pits evaluated in 1992 would reduce benthic invertebrate numbers. However, oil and grease concentrations in pit liquids were significantly lower in 1993 compared to 1992 and only 2 of 15 would affect benthic invertebrate populations.

Chemicals other than oil and grease present in pit solutions may also contribute to lethal or sublethal impacts to migratory birds. Inorganic contaminants and poor water quality caused by drilling effluent pollutants in reserve pits in Alaska were found to be potentially hazardous to wildlife (West and Snyder-Conn 1987). Results of analyses for water quality components can be used to determine the suitability of water for supporting wildlife. Water quality components were compared between years and sodium, nitrate, carbonate, hardness, and electrical conductivity were higher in pit liquids sampled in 1992 than in 1993 (Tables 6 and 7).

High salinity, as measured by electrical conductivity or total dissolved solids, is a frequent contaminant. Saline groundwater can be brought to the surface during drilling operations. Fluids with high salt concentrations are sometimes used as part of the drilling process. Few studies have been done on the toxicity of dissolved solids to birds; however, field studies have evaluated the impacts that limnological conditions have on waterfowl health in the prairie pothole wetlands of North Dakota (Swanson et al. 1984, 1988). Electrical conductivity is one of the best characteristics for determining the suitability of water for waterfowl. Gorham et al. (1983) reported that electrical conductivity is directly related to dissolved substances. They also reported that extremely high or low water levels can significantly influence conductivity and other water-quality characteristics. Precipitation can increase the volume of liquids in oil pits, resulting in a dilution of dissolved materials and a lowering of conductivity.

In 1992, electrical conductivity of pit liquids ranged from 180 to 34,100 µmhos/cm (Table 6). In 1993, electrical conductivity of pit liquids ranged from 410 to 17,000 µmhos/cm (Table 7). Electrical conductivity of 17,000 µmhos/cm significantly reduced duckling growth in a study by Swanson et al. (1984). Ducklings experienced some mortality at 16,000 µmhos/cm and could not tolerate electrical conductivities exceeding 20,000 µmhos/cm in prairie lakes unless freshwater was also available (Swanson et al. 1984). Ducks have salt glands that allow them to tolerate saline habitats. However, the salt glands of ducklings are not fully developed until they are a few days old. Birds that do not have salt glands, such as some passerine birds, rely on their kidneys to process salts (Welty 1982).

Not only is elevated electrical conductivity toxic to waterfowl, it also can be toxic to dietary items waterfowl feed upon. Invertebrates are important in the diet of waterfowl, especially young ducks. Albers et al. (1985) reported that invertebrate biomass was inversely related to the electrical conductivity of water. Electrical conductivity in 3 pits sampled in 1992 equaled or exceeded 17,000 µmhos/cm. In 1993, electrical conductivity in 1 pit equaled 17,000 µmhos/cm. The liquid in these pits could be toxic to waterfowl and many species of invertebrates.

Sodium is frequently the principal component of dissolved solids. It is an active metal that does not occur free in nature. Sodium contributes to cell osmotic pressure, and at high concentrations it is toxic to plants, and reduces soil permeability (U.S. EPA 1986). Sodium carbonate and bicarbonate are more toxic to plants than other sodium salts (McKee and Wolf 1963). Sodium was detected in all liquid samples collected in 1992 and 1993. The mean sodium concentration in 29 pit liquids collected in 1992 was 4,025.48 ppm and the range was 6.00 to 18,000.00 ppm (Table 5). The mean sodium concentration was higher in pit liquids than in waters from wetlands located west of the Missouri River in South Dakota. Sodium concentrations in 42 western South Dakota wetland waters had a mean of 349.12 ppm and a range of 6.00 to 10,100.00 ppm (Table 5). In 1993, sodium ranged between 46.00 and 4,000.00 ppm and averaged 1,049.47 ppm in 15 pit liquid samples (Table 5).

Sodium and hardness contributed significantly to pit liquid electrical conductivity in 1992 and 1993. In 1992, sodium and hardness were highly correlated with electrical conductivity ($N = 15$, $r = 0.98$, $p < 0.01$ and $N = 15$, $r = 0.77$ and $p < 0.01$, respectively). Sodium and hardness were again correlated with electrical conductivity in 1993 ($N = 15$, $r = 0.99$, $p < 0.01$) and ($N = 15$, $r = 0.64$, $p < 0.01$, respectively).

Elevated concentrations of total dissolved solids (TDS) can be lethal to aquatic organisms because osmotic pressure differences between the organism and water can dehydrate the cells of the organism, resulting in death. The safe upper limit for total salts in water for poultry is 2,800.00 ppm (McKee and Wolf 1993). Sodium salts alone exceeded this concentration in 4 pits sampled in 1992 and in 1 pit sampled in 1993. Water containing 500 to 1,000 ppm TDS can have detrimental effects on sensitive plants; and water having 1,000 to 2,000 ppm TDS can have adverse effects on many plants (U.S. EPA 1976). In our study, sodium alone in liquid samples from 14 of 30 pits equaled or exceeded the lower salt limit of 1,000 ppm that would effect plant health.

Selenium is a naturally occurring element. It occurs at low concentrations in water and soil throughout much of South Dakota; however, in some areas, it is present at high concentrations. Selenium from local sources or from produced liquids may concentrate in pits. In 1992, the mean selenium concentration in 15 oil pit liquids was 7.30 ppb and the range was 0.08 to 101.00 ppb (Tables 5 and 6). The highest concentration was detected in a Fall River County pit. Fall River County is known to have soils derived from Pierre Shale containing elevated selenium concentrations (Schultz et al., 1980). Selenium in pit liquids sampled in 1993, all in Harding County, ranged between <0.50 and 2.26 ppb (Table 5). The mean selenium concentration in 43 unpolluted waters from wetlands located west of the Missouri River was 2.58 ppb and the range was 0.31 to 13.75 ppb (Table 5). Mean selenium concentrations were highest in 1992 pit liquids; however, selenium was more elevated in west river wetlands than in 1993 oil pit liquids (Table 5).

Selenium can cause adverse effects to wildlife when it becomes concentrated in aquatic environments (Eisler 1985). Selenium concentrations in water between 2.00 and 5.00 ppb can result in bioaccumulation of selenium in dietary items, which, if consumed, may inhibit reproduction and cause mortality in birds (Lemly and Smith 1987). In 1992, selenium concentrations in samples from 1 of 15 pits exceeded 2.00 ppb (Table 6). Selenium in 1 of 15 liquid samples collected in 1993 exceeded 2.00 ppb (Table 7). Most pits sampled did not have elevated levels of selenium; however pits with selenium concentrations $\geq$ 2.00 ppb could be a potential hazard to birds feeding there.

Swanson et al. (1984) believed that high concentrations of sulfates cause greater stress on birds than equivalent concentrations of sodium chloride. Ruelle and Henry (1993) reported a strong positive correlation ($r = 0.97$) between sulfate concentrations and electrical conductivity in unpolluted South Dakota wetland waters. However, no correlation was found between electrical conductivity and sulfates in pit liquids indicating that factors other than sulfates influence electrical conductivity in the pits sampled. Illinois has a State Water Quality Standard of 500.00 ppm sulfate for water used for aquatic life purposes (U.S. EPA 1988). Liquids in 8 of 15 pits sampled in 1992 and in 9 of 15 pits sampled in 1993 exceeded 500.00 ppm sulfate (Tables 6 and 7). The highest sulfate concentration (2,938 ppm) was detected in a Harding County water sample collected in 1993.

Concentrations of alkalinity and hardness are indicators of the ability of water to buffer acid rain and other influences on pH. The pH in pit liquids collected in 1992 ranged between 6.92 and 9.12 (Table 6). The pH standard for the protection of aquatic life recommended by U.S. EPA (1976) is 6.5 to 9.0. The pH value for liquids in 2 pits exceeded the U.S. EPA standard. The pH in pit liquids (6.86 to 8.64) collected in 1993 were within the normal range expected for unpolluted South Dakota waters and were within U.S. EPA standards for the protection of aquatic life (Table 7).

Pit Liquid Toxicity

The best method for preventing wildlife mortalities at pits is to eliminate their exposure to hazardous materials. The safest way to do this is to store waste liquids in enclosed tanks until it can be reinjected back into a well. This eliminates the need for storage in open above ground facilities such as pits and half barrels. Oil and grease concentrations in pit liquids where birds died ranged from 1.00 ppm to 38.40 ppm. Liquid in 1 pit at which 4 birds were recovered had 2.88 ppm oil and grease. We could not relate bird mortalities to a specific concentration of oil and grease. Oil and grease are not evenly distributed over the water surface of pits. The wind moves oil floating on the surface of pits causing it to concentrate along the shoreline. The toxic threshold for oil and grease in water above which all exposed birds die is unknown. The toxic effects of oil and grease concentrations detected were difficult to interpret because we do not know the chemical composition of the oil compared to that used in bird toxicity studies. We also do not know what additive or synergistic toxic effects the presence of other chemicals may have to birds. Dead birds with oil on their feathers were collected from pits, the surrounding banks, and from fields bordering oil production sites; thus, suggesting mortality might be caused by the oil.

Few studies have been conducted to determine the toxic concentrations of oil and grease in water to birds. Nesting birds could accumulate oil on their feathers that would be lethal to eggs. Studies have been done on the amount of oil on feathers that can be transferred to eggs causing lethal or chronic adverse effects. A small amount of oil on an egg can cause embryo mortality. Szaro et al. (1978) found that mallard eggs (*Anas platyrhynchos*) treated with 1 to 50 μl of different kinds of oils reduced egg hatchability and chick survival, and treatments of 5 μl or more drastically reduced egg hatchability and embryo survival. Hoffman and Albers (1984) found that the LD50 for various oils applied externally on mallard eggs ranged from 0.30 to 23.50 μl. These are extremely small amounts of oil.

One pit with an oil layer thick enough to entrap birds contained 813.00 ppm oil and grease in the liquid. If birds do escape from these pits, it is highly possible that the oil will cause feather injury, impairing normal activity. The ingestion of oil from preening feathers may cause toxic effects. In 1966, Hartung and

Hunt studied the effects of cutting oil, diesel oil, and lubricating oil fed to captive and wild mallards and found that the oils were more toxic to stressed ducks kept outdoors. Oil covered birds that escape from the pits could be expected to die from exposure, starvation, or predation. Oil covered birds or contaminated birds can cause secondary poisoning to other wildlife species such as predators and scavengers.

Oil pits cause some physical and chemical effects, independently or in combination, that can lead to wildlife mortality. Birds and other wildlife suffer adverse physical effects when they become covered with oil and cannot fly, feed, or are otherwise physically incapacitated. Open pits with thick oil coverings could entrap birds and cause mortality. Chemicals incapacitate wildlife through toxic effects.

Pits with an oil sheen but no thick oil covering may not entrap birds; therefore, the fate of birds exposed to these pits is unknown. Some pits may appear clean but contain high concentrations of dissolved solids or other contaminants that affect bird health. For example, one pit sampled had only a slight visible sheen of oil unequally distributed over the surface and had an oil and grease concentration of 1.13 ppm. This pit probably would not entrap birds. We do not know if this concentration would have sublethal impacts to birds with repeated exposure. Liquid in a pit in Fall River County appeared black but did not have an oily consistency. This pit contained 7.38 ppm oil and grease in the liquid in July, and in October the pit solution was green. Chemicals discharged into the pit may have caused the green color. Another pit, which killdeer were observed using, had 460.00 ppm oil and grease in the sediments, but the liquid did not appear oily. Shorebirds may accumulate oil from highly contaminated sediment on their feet and bills . Concentrations of contaminants in pits vary depending on oil production and associated activities. Operators sometimes remove floating oil from pit surfaces. Oil sludges in the bottom sediments are removed less frequently, if at all, and may contain more concentrated contaminants.

In 1993, twenty five predator scats were collected from the same field as 17 dead birds. These unidentified scats were probably from skunk, raccoon, fox, or coyote based on predators known to be present in the area. Two of the scats contained feathers. After remaining submerged overnight in water, an oil sheen was visible on the surface of the 2 containers where feathers were found in the scats. Oil was not visible on the surface of the other containers. This is strong evidence that more than the 17 birds we collected were killed by oil exposure and that some of the dead birds were eaten or carried off by predators. The presence of oil in the scats also indicates that oil from scavenged birds passed through the digestive tracts of predators.

Hair believed to be from small mammals was detected in 11 scats. These scats also contained small mammal teeth and bone fragments. Grasshopper parts were observed in 12 of the scats.

Bioassays

In 1992, 17 of 29 radish seed assays had 100 percent germination (Table 8). Twelve of 15 radish seed assays conducted with liquid samples collected in 1993 had 100 percent germination. Scuds had better survival than daphnids in bioassays. In some bioassays with liquids that exhibited low toxicity, daphnids molted and reproduced. Only 2 control samples did not have 100 percent survival. These were young daphnids in 1992 (Table 8) and young scuds in 1993 (Table 9). The combined survival or mortality of all species exposed to any one liquid sample provided the best data concerning the presence of toxic materials in the sample.

In 1992, 14 of 27 samples had less than 80 percent survival or germination in at least 2 separate bioassays, and in 3 samples all organisms died in all bioassays (Table 8). In another 1992 assay, all invertebrates died within minutes. A duplicate bioassay conducted on this sample produced identical results. This liquid had 7.38 ppm oil and grease. Water quality analyses were not done on this sample.

In 1993 assays, young Hyalella azteca had the lowest, and adults had the highest, survival in bioassays conducted on 15 liquid samples. Daphnia magna adults and young each had 100 percent survival in 8 bioassays (Table 9). The control bioassays all had 80 percent or greater survival except for young Hyalella azteca, which had 100 percent mortality. The cause of this mortality is unknown; however, mortality in controls was not universal for all species. Daphnia in both age classes had 100 percent mortality in 3 bioassays. There were individual bioassays in which all organisms died; however, none of the samples killed all of the organisms in each of the 4 assays conducted.

Two 1992 bioassays in which daphnids did not survive had low oil and grease concentrations but high salinity. Electrical conductivity was greater than 10,000 μmhos/cm in both samples. Bioassays conducted in 1993, in which all ages of daphnids died, had electrical conductivities $\geq$ 9,200 μmhos/cm.

No organisms survived in assays conducted with a 1992 liquid sample having an electrical conductivity of 32,800 μmhos/cm. Generally, the lower the electrical conductivity, the higher the percent survival/germination of bioassay organisms. However, there was no correlation between percent survival in single-species invertebrate bioassays and electrical conductivity of pit liquids collected in 1992 and 1993. We considered less than 80 percent survival of the test organisms as an indication that the test liquid was toxic to invertebrates. In both 1992 and 1993, electrical conductivity of pit liquids was negatively correlated ($p < 0.05$) with the mean percent survival/germination of grouped bioassay organisms, Hyalella azteca, Daphnia magna, and percent radish seed germination. The mean percentage seed germination and percentage survival in all invertebrate bioassays in 1992 and 1993 was inversely correlated ($p < 0.05$) to electrical conductivity. These data suggest that high salts in liquids, that are components of electrical conductivity, suppressed the survival/germination of bioassay organisms. This hypothesis is strengthened by the relationship exhibited between electrical conductivity and survival of adult and young daphnids (Figures 2 and 3). Adult and young Daphnia magna had, with some exceptions, 100 percent survival in liquids having 7,500 μmhos/cm or less electrical conductivity. However, both ages of daphnids suffered 100 percent mortality when exposed to all liquids having 9,200 μmhos/cm or higher electrical conductivity. In bioassays conducted with larval fathead minnows and radish seeds, there was no survival or germination in water having an electrical conductivity of 30,100 μmhos/cm (Ruelle and Henry 1993).

In general, there was 100 percent germination for radish seeds exposed to liquids having electrical conductivities of 10,000 μmhos/cm or less (Figure 4). There were 4 assays where electrical conductivity was less than 10,000 μmhos/cm and seed germination was less than 100 percent. Factors other than electrical conductivity appear to be responsible for reduced germination in these assays. Seed germination started to decline at electrical conductivities of between 10,000 and 12,500 μmhos/cm and was low or nonexistent in liquids having 17,500 to 32,800 μmhos/cm electrical conductivity. Electrical conductivity at these concentrations would greatly reduce species diversity and populations of plants in and around pits. Salt concentrations of 525.00 to 1,400.00 ppm (approximately 820 to 2,190 μmhos/cm) in water are classified as permissable for plant growth, while 1,400.00 to 2,100.00 ppm (approximately 2,190 to 3,280 μmhos/cm) are doubtful for plant growth (McKee and Wolf 1963).

Toxic influences not related to electrical conductivity also appear to have reduced seed germination in several assays. Other water quality characteristics such as chlorides, sulfates, magnesium, nitrates, carbonates, and organic compounds may individually or in combination influence seed germination. The seed germination test is useful for determining if any toxic constituents are present that would inhibit germination. The test cannot predict long-term seedling survival.

High invertebrate mortalities in bioassays were not directly correlated with high oil and grease, high electrical conductivity, or high selenium concentrations. It appears that other factors such as sodium salts or organic chemicals in pit liquids also contributed to bioassay organism mortality. Sodium was highly correlated with electrical conductivity (Figure 5) and may have been a primary factor influencing toxicity of oil pit liquids. It is apparent that at least some species of lower food-chain organisms that would be important in the diet of fish and wildlife cannot survive in many of the oil pits.

CONCLUSIONS

This study contributed to the baseline data on the physical and toxicological hazards of oil pits to wildlife in South Dakota. We demonstrated that migratory birds, other wildlife, and food-chain organisms are using the pits and are being killed by the physical and toxicological effects of hazardous chemicals. Passerine birds and shorebirds appeared to suffer high mortality. Oil in scats indicated that predators feed on birds killed or weakened from being exposed to toxic oil pit liquids. Some pits may contain chemical wastes other than oil, such as drilling effluent, that can adversely impact the health of migratory birds and other wildlife. Dissolved solid concentrations high enough to be toxic to birds, benthic invertebrates, and plants were detected in pit solutions. Pit liquids contained elevated concentrations of sodium that contributed significantly to high electrical conductivity. Electrical conductivity was inversely correlated with mortality of bioassay organisms.

Methods used to eliminate or clean up pits vary widely among oil companies. The best method for preventing bird mortality at oil production sites is to temporarily store waste liquids in tanks until they can be reinjected back into the ground. The second best method for preventing bird mortality is to exclude wildlife from pit access by placing nets over the pits. Overall, there are fewer pits in use than when we started this study. Some companies are filling in pits and reinjecting liquid wastes back into the ground. Two companies are actively installing and maintaining nets to exclude birds. Service Law Enforcement officers and the U.S. Attorney's Office, working in cooperation with the oil companies, have made progress toward reducing wildlife mortality at oil production sites. Prosecution for violating the Migratory Bird Treaty Act may provide incentive for oil companies to eliminate bird mortalities.

RECOMMENDATIONS

Additional exploration and production of oil in South Dakota could cause a proportional increase in toxic threats to wildlife. Therefore, it is important that recommendations for reducing wildlife mortality associated with oil production operations be developed. Hazards to wildlife can be reduced in the oil fields by implementing the following recommendations.

1. Excluding wildlife from contact with hazardous materials is the best method for preventing wildlife mortality at oil production sites. We recommend that solutions be temporarily confined in tanks until they can be injected back into the ground. This is the best method for preventing wildlife from coming into contact with hazardous liquids.

2. We recommend that pits not be used to store liquid wastes at oil production sites.

3. Nets over pits containing liquids, are not as acceptable as tank storage and underground injection because they only exclude larger wildlife species. If pits are used to store liquid wastes, they should be covered with nets. Nets should be of the smallest mesh possible that will exclude birds and larger mammals and still be maintained under all weather conditions.

4. We recommend that half barrels or buried tanks not be used to collect liquid wastes at oil production sites. We also recommend that these liquids be stored in tanks and reinjected into the ground.

5. If half barrels are used to store liquid wastes, they should be covered with heavy wire mesh or with expanded metal that will exclude small mammals and other wildlife. The covers should be secured so that they are not easily dislodged. They should completely cover the barrel top and extend down over the sides of the barrel so that small mammals and birds cannot enter.

6. It is recommended that new technology be developed and new legislation be enacted to prevent future wildlife losses at oil production sites.

Recommendations for the prevention of wildlife injury and mortality at oil production sites may change as new exclusion methods are developed and new information becomes available.

ACKNOWLEDGMENTS

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LITERATURE CITED

Albers, P. H., A. A. Belisle, D. M. Swineford, and R. J. Hall. 1985. Environmental contamination in the oil fields of western Pennsylvania. Oil and Petrochemical Pollution 2:265-280.

Balcomb, R. 1986. Songbird carcasses disappear rapidly from agricultural fields. Auk 103:817-820.

Eisler, R. 1985. Selenium hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish and Wildl. Serv. Biol. Rep. 85(1.5).

Esmoil, B.J. 1991. Wildlife mortality associated with oil pits in Wyoming. M.S. Thesis, University of Wyoming, Laramie, WY.

Flickinger, E.L. 1981. Wildlife mortality at petroleum pits in Texas. J. Wildl. Manage. 45:560-564.

Flickinger, E.L., and C.M. Bunck. 1987. Number of oil-killed birds and fate of bird carcasses at crude oil pits in Texas. Southwestern Naturalist 32:377-381.

Gorham, E., W.E. Dean, and J.E. Sanger. 1983. The chemical composition of lakes in the north-central United States. Limnol. Oceanogr. 28(2):287-301.

Hartung, R., and G.S. Hunt. 1966. Toxicity of some oils to waterfowl. J. Wildl. Manage. 30:564-570.

Henry, C.J., and R. Ruelle. 1993. Contaminants, water quality, and wildlife mortality on oil production sites in western South Dakota. Report No. SD-ES-93-04, U.S. Fish and Wildlife Service, Pierre, SD.

Hoffman, D.J., and P.H. Albers. 1984. Evaluation of potential embryotoxicity and tetratogenicity of 42 herbicides, insecticides, and petroleum contaminants to mallard eggs. Arch. Environ. Contam. Toxicol. 13:15-27.

Holmes, W.N., K.P. Cavanaugh, and J. Gorsline. 1985. Environmental pollutants and the endocrine system: some effects of ingested petroleum in birds. Proc. 9th Internat. Symp. Comp. Endrocrin. 2:1211-1219.

Lemly, A.D., and G.J. Smith. 1987. Aquatic cycling of selenium: implications for fish and wildlife. Fish and Wildlife Leaflet 12, U.S. Fish and Wildlife Service, Wash. D.C.

McKee, J.E., and H.W. Wolf. 1963. Water Quality Criteria. Calif. State Water Resources Control Board, Sacramento, Calif.

Olsen, G.H., J.M. Nicolich, and D.J. Hoffman. 1990. A review of some causes of death of avian embryos. Proc. Assoc. of Avian Vet. 106-111.

Ruelle, R., and C.J. Henry. 1993. Contaminant and toxicity evaluation of National Wildlife Refuge and private wetlands in South Dakota. Contaminant Report Number: R6/814P/93, U.S. Fish and Wildlife Service, Pierre, SD.

Schultz, L.G., H.A, Tourtelot, J.R. Gill, and J.G. Boerngen. 1980. Composition and properties of the Pierre Shale and equivalent rocks, Northern Great Plains Region: U.S. Geological Survey professional Paper 1064-B, 114 p.

South Dakota Administrative Rules. 1987. Oil and gas conservation. SD Dept. of Environment and Natural Resources, Pierre, SD.

Swanson, G.A., V.A. Adomaitis, F.B. Lee, J.R. Serie, and J.A. Shoesmith. 1984. Limnological conditions influencing duckling use of saline lakes in south-central North Dakota. J. Wildl. Manage. 48(2):340-349.

Swanson, G.A., T.C. Winter, V.A. Adomaitis, and J.W. LaBaugh. 1988. Chemical characteristics of prairie lakes in south-central North Dakota--their potential for influencing use by fish and wildlife. U.S. Fish Wildl. Serv. Tch. Rep. 18.

Szaro, R.C., P.H. Albers, and N.C. Coon. 1978. Petroleum: effects on mallard egg hatchability. J. Wildl. Manage. 42(2):404-406.

U.S. EPA. 1976. Quality Criteria for Water 1976. U.S. EPA, Washington, D.C.

U.S. EPA. 1986. Quality Criteria for Water 1986. U.S. EPA, Washington, D.C. EPA 440/5-86-001.

U.S. EPA. 1988. State Water Quality Standards Summaries. U.S. EPA Office of Water, Washington, D.C. EPA Publication Number 440/5-88-031.

Welty, J.C. 1982. The life of birds. Third edition. Saunders College Publishing.

West, R.L., and E. Snyder-Conn. 1987. Effects of Prudhoe Bay reserve pit fluids on water quality and macroinvertebrates of arctic tundra ponds in Alaska. U.S. Fish and Wildl. Serv., Biol. Rep. 87(7).

Woodward, D. F., and R. G. Riley. 1983. Petroleum hydrocarbon concentrations in a salmonid stream contaminated by oil field discharge water and effects on macrobenthos. Arch. Environm. Contam. Toxicol. 12, 327-334.

Table 1. Locations of pits studied in Fall River and Harding Counties, South Dakota, 1992.

I.D. No.	Location		Company	Site Name	Wildlife Exclusions	Comments
1	T21N, R4E, S17 Harding County	NESE	Koch	–	–	Pit present in April. Pit filled in by July.
A1	T21N, R4E, S9 Harding County	NENE	Koch	Clarkson 14-4	Netted	Dead killdeer collected.
10	T21N, R4E, S28 Harding County	SWSW	Koch	SBRRU CTB 10	No net	Dead bat in barrel. Live insects in pit.
11	T20N, R4E, S11 Harding County	SWNE	Koch	SBRRU CTB 11	No net	New pit.
13	T20N, R4E, S10 Harding County	SENE	Koch	SBRRU CTB 13	Netted	Dead bird collected.
135	T23N, R4E, S28 Harding County	–	Petro Lewis	Marathon Kenton Field	No net	Tadpoles in pit.
136	T23N, R5E, S22 Harding County	SENE	Luft	–	–	Open barrel.
144	T22N, R5E, S6 Harding County	SWSE	Luff	Travers 1-6	No net	Oil sheen on half of pit surface.
151	T20N, R5E, S16 Harding County	SENE	Cenex	State Cave Hills	No net	Light oil sheen
155	T23N, R6E, S27 Harding County	NWSE	Luff	Miller 1-27	No net	Open half barrels.
157	T22N, R5E, S5 Harding County	NE	Luff	Janvrin 1-5	No net	Oil sheen over 80% of surface.
157P	T22N, R4E, S1 Harding County	SWSE	Koch	Hansen State 34-1	No net	Separator pit at site 420.
174	T23N, R6E, S19 Harding County	SENW	Luff	Dworshak 1-19	No net	Pit surface 100% oil covered.
175	T12S, R1E, S16 Fall River County	–	Advantage	Advantage 4-16 State	No net.	Dead mice in half barrel.
179	T9S, R2E, S15 Fall River County	SWSENW	L & J	Wuff Fed # 1	No net.	Duck feathers, 8 dead rabbits, and 1 mouse. Pit now filled in.

Table 1. Continued, Page 2.

I.D. No.	Location		Company	Site Name	Wildlife Exclusions	Comments
210	T23N, R6E, S30 Harding County	NESE	Luff	Dworshak 1-30	No net.	Pit 100% oil covered, open top half barrel.
214	T23N, R6E, S32 Harding County	SW E 1/2	Luff	Swanson 1-32	No net	Dead mouse in half barrel.
216	23N, R5E, S25 Harding County	NENW	Luff	Erickson 1-25	No net	Live tadpoles and inverts in pit.
218	T20N, R4E, S4 Harding County	SESW	Koch	SBRRU 20	No net.	--
220	T22N, R6E, S11 Harding County	NENE	Luff	Fiest 1-11	No net.	Two dead mice in half barrel.
227	T11S, R1E, S3 Fall River County	NESE	Placid	-	No net	Barrels covered.
241	T21N, R5E, S25 Harding County	SESW	CENEX	Brown 25-14	No net.	Live frogs in pit; slight sheen.
299	T21N, R5E, S25 Harding County.	NWNW	Snyder	Brown 11-25	No net.	One dead swallow recovered from pit. Geese nesting in wetland below pit.
420	T22N, R4E, S1 Harding County.	SWSE	Koch	Hansen State 34-1	No net	Sheen on small part of pit
430	T22N, R3E, S16 Harding County.	NWNW	Koch	State CTB 4	Netted	Sheen on part of pit.
438	T22N, R4E, S18 Harding County.	NESE	Luff	--	No net.	Flagging.
454	T21N, R3E, S22 Harding County.	NWSW	Apache	Clarkson 13-22	No net.	Horned larks observed using pit.
460	T20N, R4E, S7 Harding County.	NWNW	Koch	Travers 1	No pit.	Pit present in April; pit filled in by July.
464	T21N, R3E, S21 Harding County.	NESE	Apache	Clarkson 9-21	Flagging	Four dead birds recovered.
478	T21N, R3E, S16 Harding County.	SESE	Apache	State 44-16	No net.	No oil sheen. Bird tracks around pit.
488	T21N, R3E, S22 Harding County.	NWNW	Apache	Clarkson 6-22	No net.	No oil sheen.

Saved as B:oil Disk: DC-1
Columns A to H, Lines 59 to 170

Table 2. Locations of pits studied in Harding County, South Dakota, 1993. I.D. No.'s 93-3-W and 93-5-W were sampled in 1992 as No.'s 151 and 144 respectively (Table 1).

I.D. No.	Location		Company	Site Name	Wildlife Exclusions	Comments
93-1-W	T20N, R5E, S26	-	Cenex	Cenex No. 26-5	Flags	No aquatic life
93-2-W	T20N, R5E, S15	NWSW	SOCO Snyder	Johnson 13-15	Flags	No aquatic life
93-3-W	T20N, R5E, S16	SENW	Cenex	State Cave Hills No. 1	N/A	Drain pipe effluent
93-4-W	T20N, R6E, S7	NESE	Cenex	Turbiville 7-9	Flags	Dead horned lark No insects or zooplankton
93-5-W	T22N, R5E, S6	SWSE	Luff	1-6 Travers Ranch	Flags	No insects or zooplankton
93-6-W	T23N, R5E, S19	NWSE	Luff	State Line Field 1-19	Flags	Cattails growing in pit.
93-7-W	T22N, R4E, S17	SWSW	Luff	Luff M-17	Flags	Small pit, oil buried under sediments
93-8-W	T22N, R4E, S20	SWSE	Luff	Luff No. 0-20	Flags	Oil on surface.
93-9-W	T21N, R5E, S36	NWSE	Cenex	Cenex 36-10	None	No zooplankton. Oil sludge in pit buried under silt.
93-10-W	T21N, R5E, S25	NWNW	SOCO Snyder Oil	Brown 11-25	Flags	No zooplankton or insects
93-11-W	T23N, R4E, S30	NWNW	Abraxsas	Stearns No. 2	Flags	Small pit, thick oil on surface
93-12-W	T23N, R4E, S28	-	Petro Lewis	Buckley 33-28	Unnetted	Live zooplankton living in pit.
93-13-W	T22N, R5E, S6	NESE	Luff	2-6 Travers Ranch Injection	Unnetted	Flags over pit.
93-14-W	T21N, R5E, S25	SESW	Cenex	Brown 25-14	None	Appears abandoned, dead bird found at pit edge
93-15-W	T23N, R6E, S19	SENW	Luff	Luff No. 1-19	Flags	Appears abandoned

Saved as B:oil Disk: DC-1

Table 3. Concentrations of oil and grease in liquid (ppm) and sediment (ppm dry weight) samples from oil production sites in Harding and Fall River Counties, South Dakota 1992.

Sample I.D. No.	Oil and Grease in Liquid	Oil and Grease in Sediments	Percent Moisture in Sediments
1	0.56	23700.00	37.6
A1	1.75	16900	34.4
10	1.38	--	–
11	–	460.00	31.8
13	2.50	68000	43.4
135	–	2160	47.2
136	3.13	7280.00	42.8
144	3.75	18400.00	58.2
151	7.25	3910.00	32.8
155	1.88	82600.00	34.2
157	226.00	48300.00	62.8
174	4.50	66900.00	27.0
*175A	7.38	2400.00	42.4
*175B	7.38	2400.00	42.4
186	–	18500	63.8
179	38.40	212000.00	39.8
210	12.80	32700.00	36.4
214	–	29700	43.2
216	–	22600.00	43.2
218	2.13	23800.00	27.0
220	813.00	8240.00	43.8
227	31.10	34800.00	38.2
241	1.13	8900.00	58.2
299	1.00	54100.00	70.4
420	42.60	13300.00	56.4
430	0.50	–	–
438	2.25	55400.00	59.6
454	0.50	710.00	57.4
460	0.88	17000.00	79.2
464	2.88	25100.00	35.6
478	0.63	768.00	54.4
488	0.38	853.00	74.8
Mean	46.74	30135.42	

* Duplicate sample.

Saved on C Drive as oilpits/oilgreas, on lines 33 to 67, columns G to L

Table 4. Concentrations of oil and grease in liquid (ppm) and sediment (ppm dry weight) samples from oil production sites in Harding County, South Dakota 1993. I.D. No.'s 93-3-W and 93-5-W were reported in 1992 as No.'s 151 and 144 respectively (Table 3).

Sample I.D. No.	Oil and Grease In Liquid	Oil and Grease In Sediments	Percent Moisture In Sediments
93-1-W	0.00945	32875	56.0
93-2-W	0.00522	26135	67.9
93-3-W	0.00053	670782	40.6
93-4-W	0.00174	18789	46.6
93-5-W	0.00115	17758	59.8
93-6-W	0.00588	10212	26.7
93-7-W	0.00102	18130	55.8
93-8-W	0.59000	1690	54.9
93-9-W	0.00145	273655	64.3
93-10-W	0.00250	1000000	54.0
93-11-W	1.64984	764859	28.3
93-12-W	0.00135	6271	43.1
93-13-W	0.00926	9601	42.5
93-14-W	0.00084	38294	49.5
93-15-W	0.00832	460496	42.6
Mean	0.1526	249969.8	

Saved on C drive as oilpits/oilgreas, on line 1, columns g to L

Table 5. Mean and range concentrations for sodium (ppm), selenium (ppb) and electrical conductivity (umhos/cm) in 1992 and 1993 oil pit liquids compared to water in creeks, ponds, and emergent wetlands west of the Missouri River, South Dakota.

Type of Sample	Number	Sodium	Number	Selenium	Number	Electrical Conductivity
1992 Oil Pits	29		15		15	
Mean		4,025.48		7.30		8,762
Range		6.00 to 18,000.00		0.08 to 101.00		180.00 to 34,100.00
1993 Oil Pits	15		15		15	
Mean		1049.47		0.55		4879.33
Range		46.00 to 4000.00		<0.50 to 2.26		410.00 to 17000.00
Wetlands	42		43		20	
Mean		349.12		2.58		1,837,86
Range		6.00 to 10,100.00		0.31 to 13.75		150.00 to 35,000.00

Disk: Drafts, Saved as: Opits
On Columns A to G, Lines 1 to 27

Table 6. Liquid quality characteristics in oil pits, Harding and Fall River Counties, South Dakota, July 1992. All units are in ppm except for electrical conductivity (umhos/cm), sodium (%), selenium (ppb), and pH.

Site	Selenium	Sodium	Sulfate	Nitrate	Bicarbonate HCO3	Carbonate CO3	Hardness as CaCO3	Phenolphthalein Alkalinity	Methyl Orange Alkalinity	Conductivity	Sodium % Cations	pH
A1	0.57	3600	694	2.130	88	48	1240	80	72	17,600	86.32	8.22
10	0.66	680	470	0.005	29	48	260	80	24	3500	85.04	9.12
13	1.26	410	942	0.005	137	10	640	16	112	2900	58.21	8.27
144	0.53	3400	679	2.142	122	34	640	56	100	14,700	92.03	8.26
151	0.34	1230	1365	1.090	307	0	544	0	252	6300	83.10	6.98
155	0.36	45	23	0.005	142	0	80	0	116	340	55.06	7.74
157	0.06	1160	1419	1.002	293	0	588	0	240	6400	81.09	7.03
157P*	0.38	7600	434	13.95	220	0	1740	0	180	34,100	90.47	7.32
174	0.32	138	66	0.072	225	0	180	0	184	600	62.50	7.17
214	0.58	6	24	0.005	76	0	68	0	62	180	16.05	7.60
216	0.56	350	14	0.005	249	0	204	0	204	1950	78.86	7.61
220	0.65	37	18	0.005	190	0	130	0	156	360	38.24	7.52
227	101.00	320	1658	0.005	195	0	1730	0	160	3800	28.67	7.10
420	2.00	9700	1533	0.005	337	0	1600	0	276	32,800	92.95	6.92
430	0.16	1520	1493	0.005	264	125	116	208	216	5900	96.61	9.02

* Sample from separator pit at Site 420.

Saved on C Drive as: oilpits/waterqual: Rows 1 to 26; Columns A to M.

Table 7. Liquid quality characteristics in oil pits, Harding County, South Dakota, June 1993. All units are in ppm except for electrical conductivity (umhos/cm), sodium (%), selenium (ppb) and pH. I.D. No.'s 93-3-W and 93-5-W were reported in 1992 as No.'s 151 and 144 respectively (Table 6).

Site	Selenium	Sodium	Sulfate	Nitrate	Bicarbonat HCO3)	Carbonate (CO3)	Hardness (CACO3)	Phenolphthalein Alkalinity	Methyl Orang Alkalinity	Conductivity	Sodium % of Cations	pH
93-1-W	<0.50	830	1077	0.005	254	0	700	0	208	4700	72.05	7.37
93-2-W	<0.50	1080	1221	1.535	205	10	680	16	168	5800	77.54	8.16
93-3-W	<0.50	1270	1307	0.005	278	34	640	56	228	6200	81.18	8.36
93-4-W	<0.50	1040	1218	1.359	268	5	540	8	220	5000	80.72	8.12
93-5-W	<0.50	2700	895	0.005	190	24	484	40	156	10700	92.38	8.3
93-6-W	<0.50	46	24	0.557	239	0	156	0	196	470	39.06	8.04
93-7-W	2.26	70	516	0.230	44	0	400	0	36	1050	27.54	7.03
93-8-W	0.64	59	152	1.091	29	0	72	0	24	410	64.09	7.56
93-9-W	0.76	590	1019	0.345	205	19	420	32	168	3400	75.33	8.44
93-10-W	<0.50	1060	1198	2.275	532	67	208	112	436	4700	91.72	8.64
93-11-W	0.77	58	17	0.005	68	0	48	0	56	410	72.41	7.43
93-12-W	0.66	4000	437	7.035	115	0	800	0	94	17000	91.57	6.86
93-13-W	<0.50	310	47	0.005	132	0	128	0	108	1900	84.04	7.11
93-14-W	0.61	2300	2938	0.503	361	62	360	104	296	9200	93.28	8.45
93-15-W	0.54	330	516	0.005	498	0	580	0	408	2250	55.3	7.53

Saved on C Drive as: oilpits/Waterqual; Rows 1-23, columns S to AG

Table 8. Results of 96-hour bioassays in which radish seeds and the invertebrates *Daphnia magna* and *Hyalella azteca* were exposed to liquids collected from oil pits in Fall River and Harding Counties, South Dakota 1992.

Site	Percent Germination	Percent Survival: *Hyalella azteca* Young	*Hyalella azteca* Adult	*Daphnia magna* Young	*Daphnia magna* Adult	Condition of Pit Surface
1	100	–	–	–	–	
A1	80	83	80	0	0	Oily
10	100	–	–	–	–	Slight sheen
11	100	86	83	100	100	No sheen
136	100	63	60	100	86	Slight sheen
144	100	60	83	0	0	Sheen
151	100	50	83	0	100	Slight sheen
155	100	100	80	100	80	Slight sheen
157	0	0	0	0	0	Sheen
174	100	100	83	100	100	Sheen
*175A	0	0	0	0	0	No sheen
*175B	0	0	0	0	0	No sheen
179	100	100	80	50	40	Oily
210	100	100	100	100	100	Sheen

* Duplicate samples.

Table 8. Continued, Page 2.

Site	Percent Germination	Percent Survival: *Hyalella azteca* Young	*Hyalella azteca* Adult	*Daphnia magna* Young	*Daphnia magna* Adult	Condition of Pit Surface
216	90	78	100	83	100	Slight sheen
218	90	75	100	86	100	Slight sheen
220	100	–	–	–	–	Oily
227	100	86	100	0	17	Sheen
241	50	0	14	0	0	Slight sheen
299	100	71	100	14	71	Oily
420	0	0	0	0	0	Slight sheen
430	100	–	–	–	–	No sheen
438	100	100	60	100	100	Sheen
454	100	100	100	33	13	No sheen
460	100	100	100	100	67	No sheen
464	30	60	86	0	0	Slight sheen
478	100	100	100	80	67	No sheen
488	100	100	83	0	0	No sheen
Control	100	100	100	71	100	N/A

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Columns A to I.

Table 9. Results of 96-hour bioassays in which radish seeds and the invertebrates Daphnia magna and Hyalella azteca were exposed to liquids collected from oil pits in Harding County, South Dakota 1993. I.D. No.'s 93-3-W and 93-5-W were reported in 1992 as No.'s 151 and 144 respectively (Table 8).

Site	Percent Germination	Percent Survival				Condition of Pit Surface
		Hyalella azteca		*Daphnia magna*		
		Young	Adult	Young	Adult	
93-1-W	100	100	66	100	100	-
93-2-W	100	75	100	100	66	-
93-3-W	100	100	100	20	100	No sheen
93-4-W	100	60	100	100	100	No sheen
93-5-W	100	0	100	0	0	-
93-6-W	100	20	100	100	100	-
93-7-W	100	20	50	20	16	-
93-8-W	100	80	100	100	60	Oil on surface
93-9-W	100	66	100	86	100	-
93-10-W	100	80	100	100	100	-
93-11-W	90	100	100	0	60	Oil on surface
93-12-W	80	40	80	0	0	Oil around edges
93-13-W	100	60	100	100	100	No sheen
93-14-W	100	40	100	0	0	Slight sheen
93-15-W	90	60	100	100	100	-
Control	100	0	100	80	100	

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Columns L to U, Rows 4 to 35

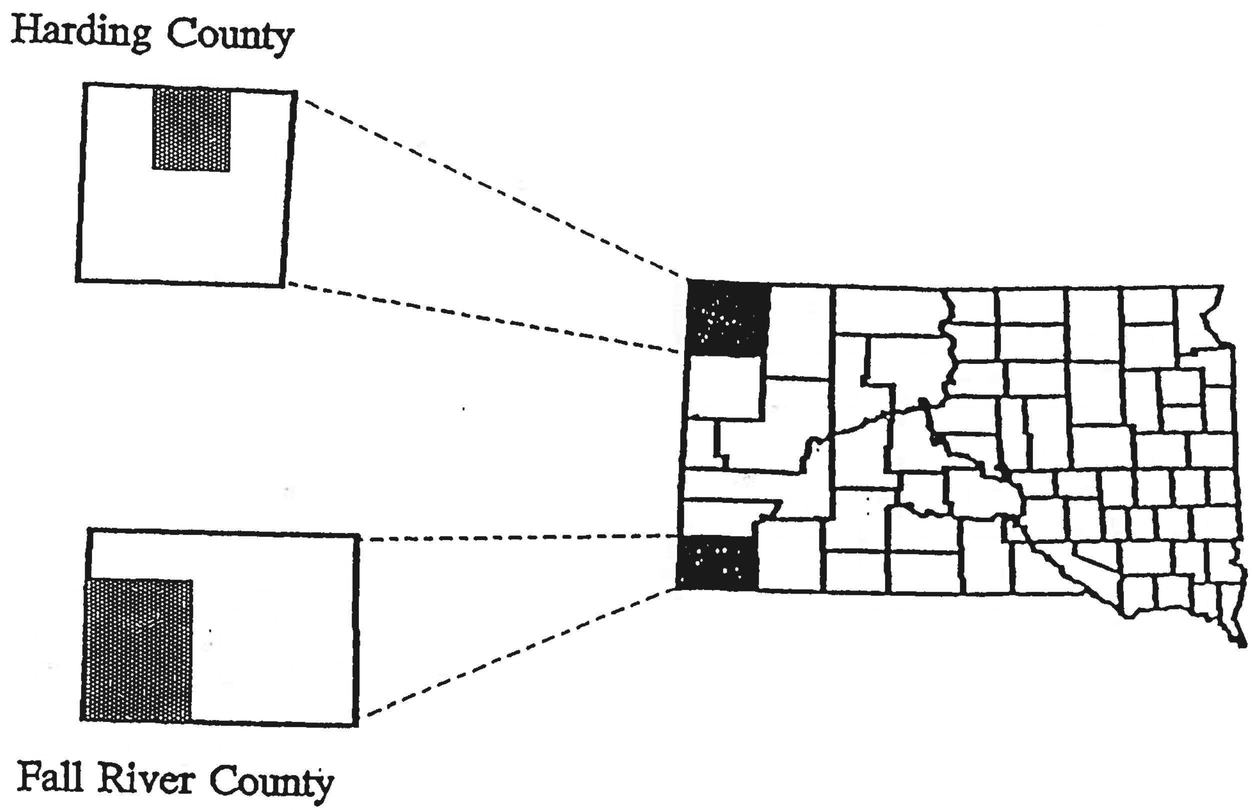

Figure 1. Locations of oil pit study areas in South Dakota, 1992 and 1993.

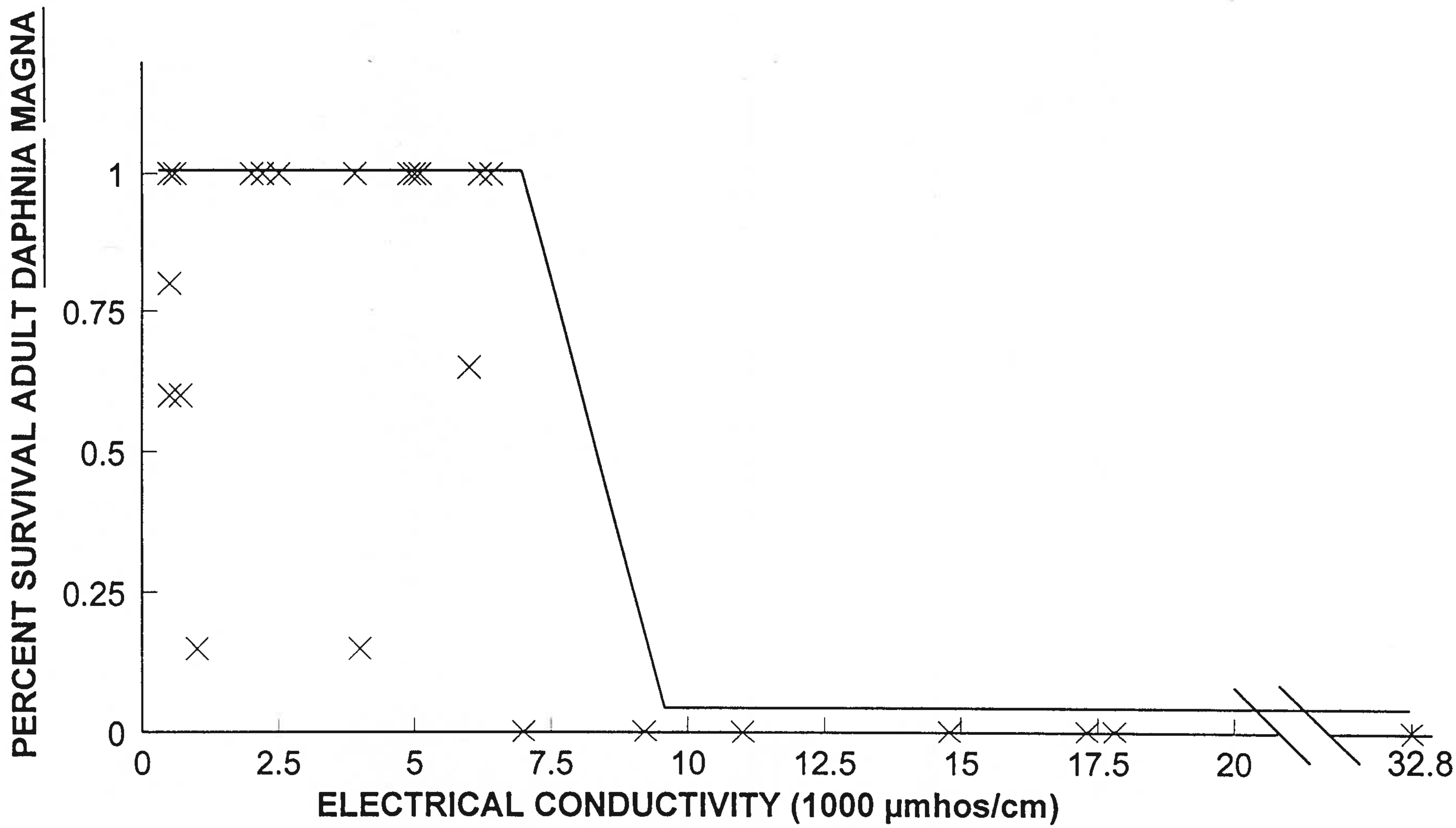

Figure 2. Comparison of electrical conductivity (1000 µmhos/cm) in liquids with percent survival of adult Daphnia magna exposed to the same liquids. Liquids were collected from pits at oil production sites in Fall River and Harding Counties, South Dakota, 1992-1993.

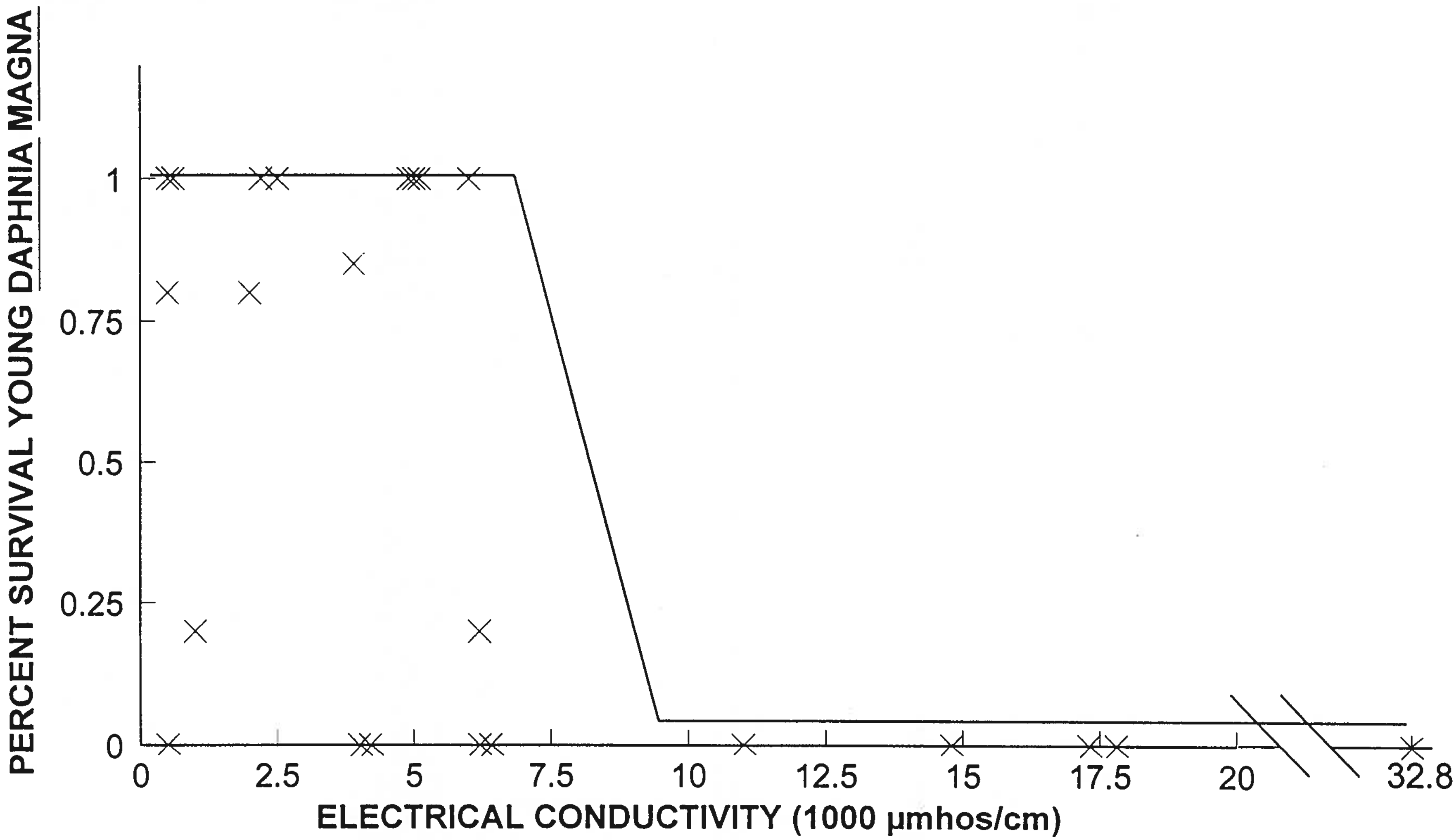

Figure 3. Comparison of electrical conductivity (1000 µmhos/cm) in liquids with percent survival of young Daphnia magna exposed to the same liquids. Liquids were collected from pits at oil production sites in Fall River and Harding Counties, South Dakota, 1992-1993.

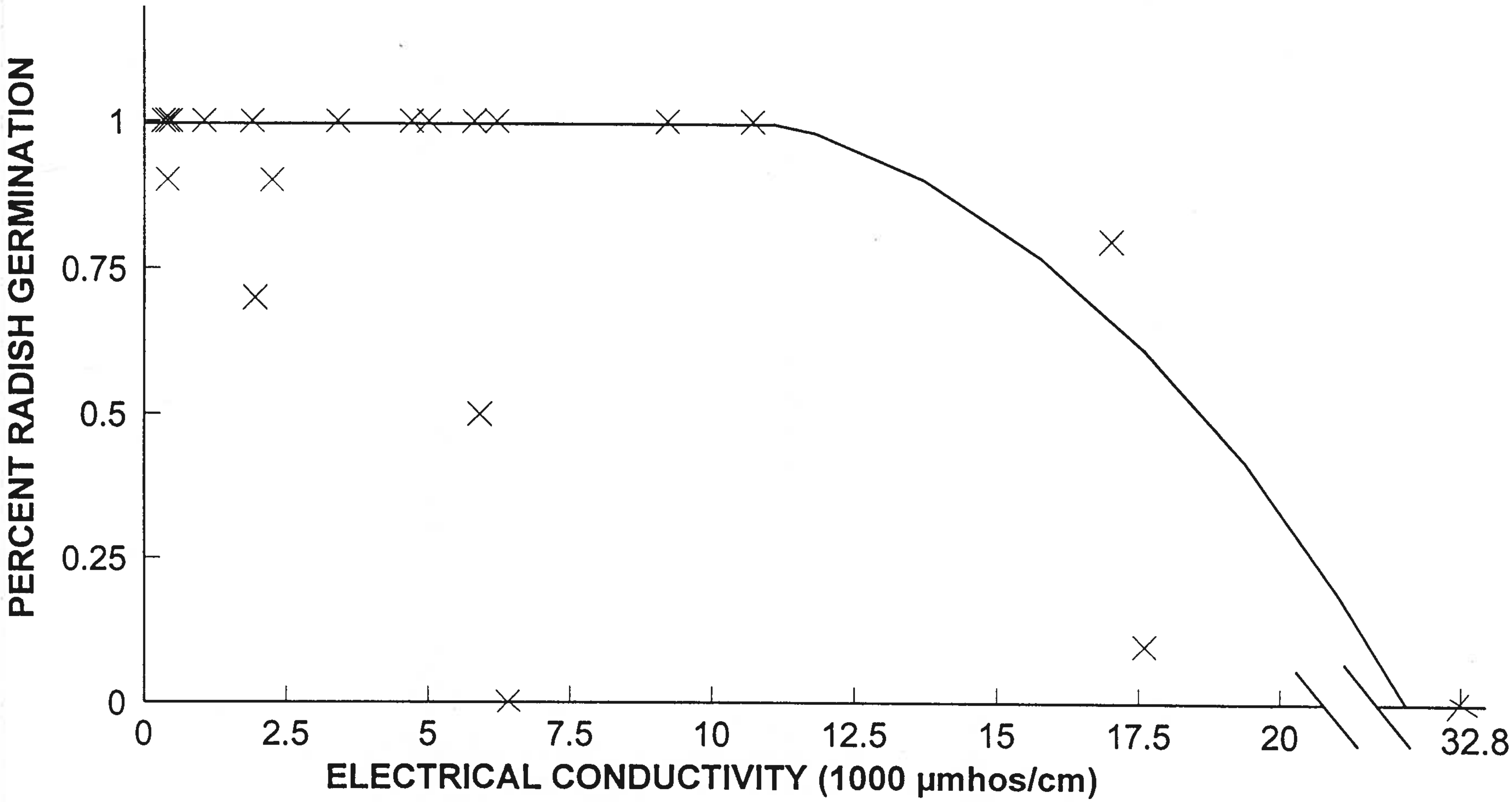

Figure 4. Comparison of electrical conductivity (1000 µmhos/cm) in liquids with percent germination of radish seeds exposed to the same liquids. Liquids were collected from pits at oil production sites in Fall River and Harding Counties, South Dakota, 1992-1993.

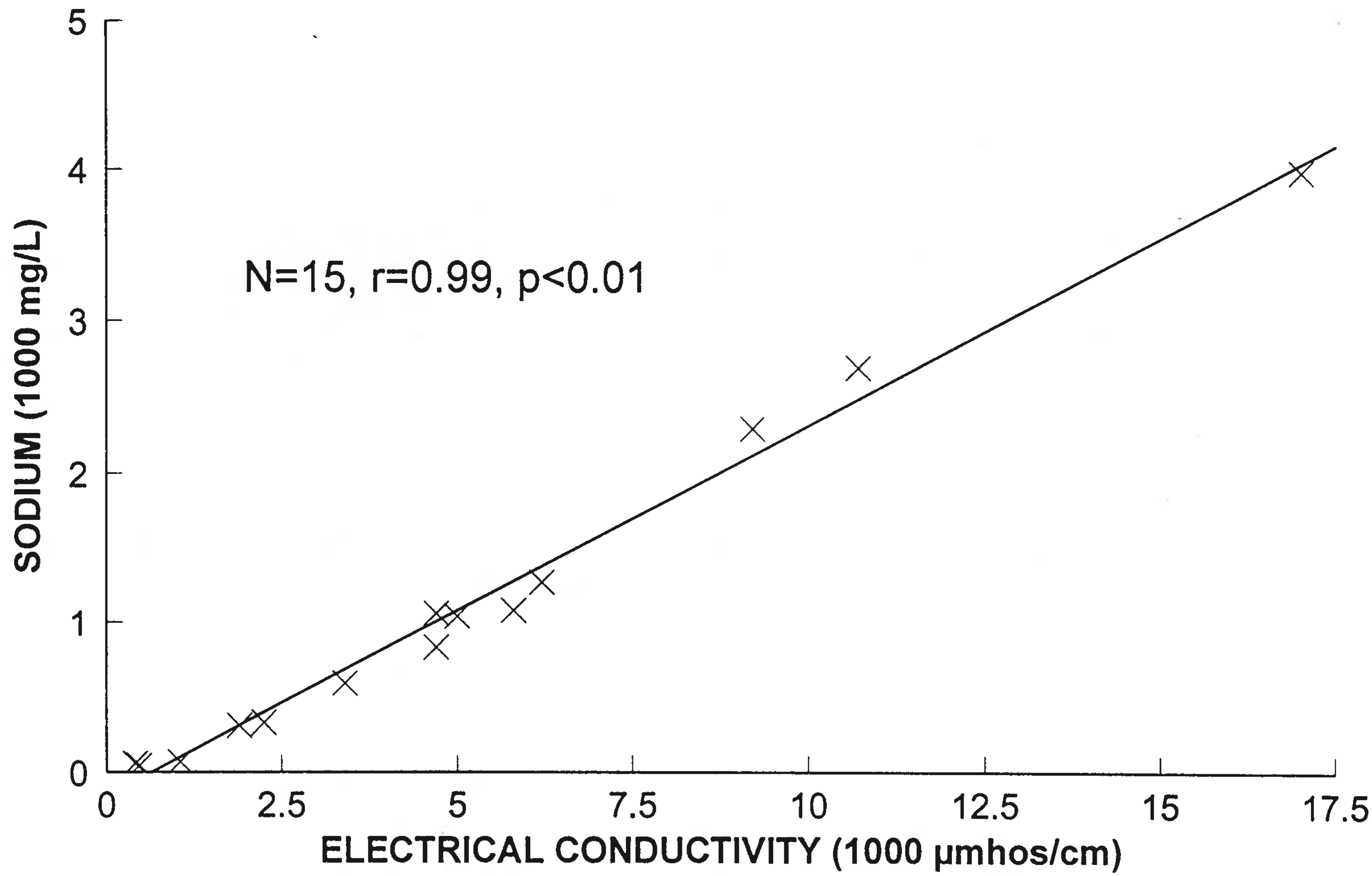

Figure 5. Comparison of electrical conductivity (µmhos/cm) and sodium (mg/L) in liquids collected from pits at oil production sites in Harding County, South Dakota, 1993.